Surface Habitation and Science Lab Systems

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Assessment Report Contents

1. Major elements of the “tall pole” (for a long-stay surface mission) and key characteristics:
   a. Basic description: “sub-poles,” key technologies/capabilities
   b. Why this is a “tall pole” and why does this need to be developed
      i. Why this is challenging
      ii. Why this is achievable (with substantive reasons: e.g., high TRL, advanced SOA, few or no “miracles” required
2. Development plan(s) or options, if any, to make this achievable:
   a. Milestones, investment strategy and priorities,
   b. Precursor and demonstration site(s), where is this being developed (US aerospace, NASA, academia, internationals?),
   c. Time to close “tall pole”
      i. Planned or expected time to close, including “sub-poles”
      ii. Required time to close, if different from i
   d. Creative alternatives, if any, for accelerating closing
3. Gaps, shortcomings, or missing elements, so far as is known, in current “tall poles” and their plans (e.g., lack of precursors/demos, disconnect among schedules, irrelevance to scenarios)

0. Assumptions, Dependencies, and Constraints

Assumptions

- ISS lessons learned; in-space transit hab will be (at least) designed, maybe flown
- Multiple visits to single site (an “outpost” as opposed to Apollo-style multiple sites)
- Long duration (as opposed to short stay, and with possible allowance for gradually building up to “long duration”)
- Crew of 6 astronauts
- Primary power from external source
- Primary communication infrastructure for communication with Earth is external to / separate from habitat

Dependencies and Constraints

- Lander: deck dimensions, maximum mass, CG
- Human interaction with Martian material

Circular relationship between surface habitat / science laboratory capabilities and capabilities of other systems (e.g., lander): choices were made in this assessment, but other implementations or architectures would lead to different tall poles.

Habitat Functional Capabilities Assumed for this Assessment

- ECLSS
- Crew quarters
- Galley and “wardroom”
- Crew health/medical
- Crew exercise
- Crew hygiene facilities
- Consumables and equipment stowage (dry, cold, and room temp)
- Trash stowage
- Air/gas/water stowage
- EVA stowage
- EVA maintenance (general maintenance?)
- Airlock / suitlock

- Listing these functional capabilities here to help identify “tall poles” and link them to functions

Issues Identified for Surface Hab /Lab Systems "Tall Pole"

- Fourteen issues identified
- These issues (dubbed "sub poles") were divided into three categories:
  - Major
  - Medium
  - Minor
- All fourteen "sub poles" captured here; only the major "sub poles" assessed for this workshop

- (Intended to be a representative, not comprehensive, list)

1. *Major* Sub-Poles

Difficult problems that need to be addressed before the first human mission and are typically independent of overall architecture or mission design.

- Systems Availability
- Mitigating Martian Natural Surface Environment *(overlap with Human Factors)*
- Fundamental and Applied Research
- Surface Habitability
- Dormancy and Startup

1. *Medium* Sub-Poles

Issues that must be addressed before the first mission but cannot be addressed before a specific architecture and/or system/element design has been selected.

- Surface operations
  - EVAs (if needed) out of the hab (including suit maintenance)
  - Rover docking
  - Logistics module docking
  - Repair/on-board fabrication
  - Leveling and docking systems for Habs (modules)
  - System architecture (modular vs. monolithic)
- Fundamental and applied research
  - Single research lab vs. mobile elements
- Close coordination with lander and EDL design
  - Habitat concepts that do not require offloading
  - Habitat integration into the lander into much more detail
  - Crew operations immediately following landing (first 1-2 weeks)
- Food? (viability vs. shelf life; overlap with Sustainability)

1. *Minor* Sub-Poles

Issues that are not as important as above items ***or*** issues that can be deferred until after the first human mission.

- Surface operations
  - Base layout
- Habitat packaging
  - Use of inflatables, aluminum and composites
- Ability to (easily) upgrade systems over habitat lifetime (closely related to maintainability) – e.g., Hubble OpsCon
- Fundamental and applied research
  - Surface research investigations – equipment needed

1a. Sub-Pole: Systems Availability

- Systems availability - Reliability and maintainability of all systems for operational lifetimes up to about 20 years
  - Why (challenge) – Limited resupply and lack of abort opportunities require that life-critical capabilities (e.g., remove CO2, generate O2, etc.) remain active or “available” for the majority of the mission.
    - Large numbers of fully redundant spares or orbital replacement units (ORUs) are not feasible within constrained habitat masses.
    - Additionally, for surface systems, the difficulty of access increases the importance of long lifetimes of components and system reliability.
  - Why (attainable) – Increased reliability, strategic system modularity, and improved maintainability of systems at component levels enable system availability.
    - Many current medium TRL (4-6) development efforts are addressing availability concerns.

2a. Development Plans: Systems Availability

- Systems availability - Reliability and maintainability of all systems for operational lifetimes up to about 20 years
  - Strategies: Combination of increased system reliabilities, ease of maintainability access, risk-based sparing, just-in-time sparing, in-situ spares manufacturing, and common tooling
  - Technologies: in-situ manufacturing, increased reliability systems.
  - Developers: NASA, (mainly US) Aerospace, Academia
  - Demonstrations: ground, ISS, and cislunar testing of desired technologies demonstrating improved MTBFs and quality
  - Expected time to close: 10-15 years
  - Need date: late 2020s.
  - Acceleration strategies: Crowd sourcing spaceflight hardware manufacturing, reduced closure life support system trades. Incorporate NEXTStep2 lessons learned.

1b. Sub-Pole: Mitigating Martian Natural Surface Environment

- "Typical" Martian environmental concerns for human missions
  - Environmental "big three":
    - Partial gravity – the effects of the Martian 3/8 gravity on human biological functions and system functionality (e.g., fire suppression (others?)) is unknown and could be significant for health and safety reasons. This is particularly problematic since there is no easy way to simulate partial gravity
    - Dust – the effects of dust on both human tissues and manufactured surfaces could be problematic for health reasons, but could also contribute significantly to wear and tear on components
    - Radiation – the effects of radiation on human tissue could be problematic for health reasons, but radiation could also affect manufactured components contribute significantly to degradation or wear and tear on components
  - Planned activities (e.g., "many" EVAs, driving rover in varied terrain, "slips/trips/falls," etc.) create opportunities for accidents
- The surface environment has benefits as well as detriments – both must be considered simultaneously and must be weighed against the alternative (micro-gravity, orbital/interplanetary space)
  - Partial gravity on the surface likely less detrimental than micro-gravity in orbit
  - Cumulative radiation exposure will be lowered due to shielding effects of planet mass and atmosphere
- *What environmentally induced/associated hazards can/should the surface habitat mitigate?*

1b. Sub-Pole: Mitigating Martian Natural Surface Environment

- "Environment" related questions for the surface habitat:
  - What surface materials are a health risk to the crew? What is an acceptable level of infiltration of any surface material into the habitat?
  - What is the probability of decompression sickness (DCS) versus cumulative EVA time? Does the habitat need hyperbaric chamber and associated floor space (if we do not have an airlock)? Do EVA hours need to be constrained?
  - What is the probability of accident induced trauma (think slips/trips/falls, accidents during maintenance/repair, etc.) versus time on the surface? Does the habitat need a dedicated medical facility (set up primarily for accidents/trauma)? Or dual use of some other space?
  - How much exercise is required given that the crew is performing "routine" and non-routine (e.g., EVA) activity in a gravity environment? Does the habitat need dedicated floor space for exercise?
  - Does the habitat need a designated (dedicated?) space for isolation/quarantine of crew exhibiting unexpected / unexplained medical symptoms?
  - How should the surface habitat be configured and what additional capabilities are needed for crew transition from micro-gravity to partial gravity?

Consider: Crew Support on Arrival at (a) Earth, (b) Mars

(a) What a “typical” ISS crew can expect to see on return to Earth

(Expedition 36: CDR Pavel Vinogradov, Alexander Misurkin, Chris Cassidy)

Crew support for ISS Expedition 6 (CDR Ken Bowersox, Nikolai Budarin, Don Petit)

(b) AND what the Mars surface crews can expect to see

2b. Development Plans: Mitigating Martian Natural Surface Environment

- Strategies:
  - Expand/refine characterization of surface environment
    - Radiation data from RAD
    - Ongoing investigations by surface rovers
    - *Gap: additional focus on (airborne) dust and fine particulates that are likely to stick to EVA suits and equipment*
  - Ongoing HRP studies
    - ISS crews
    - Bed-rest
    - Analogs (e.g., HERA)
  - Expedition medicine studies and technologies
  - *Needed: systematic identification and characterization of crew risks (with emphasis here on environmentally-induced), risk-leveling, and policy or standards for acceptable level of crew's aggregate risk exposure*
- Technologies: TBD (dependent in part on acceptable risks).
- Developers: NASA, other national space agencies, aerospace industry, medical industry, academia.
- Demonstrations: ground, ISS, and cislunar(?) testing of desired technologies, medical countermeasures, and operational procedures
- Expected time to close: 10-15 years
- Need date: late 2020s.
- Acceleration strategies: TBD

1c. Sub-Pole: Fundamental and Applied Research

- Fundamental and applied research
  - Environmental monitoring
    - Why - Human presence will alter the Mars environment. Scientific research requires understanding of pristine Mars environment (prior to human presence) and recognition of changes in Mars environment after humans arrive. Understanding how environment evolves will be critical for understanding spread of human-related biology and establishment of habitable zones due to altered environment, also identification of toxicity to humans and evolution of toxic properties of Mars materials.
  - ISRU processing (overlap with Mars Surface Power)
    - Why – On Earth, release of resource processing waste can be a significant pollutant and resource extraction and processing will alter the local Mars geology and environment (For instance, removal of surface mass could induce seismic responses, or mass movements.) Additionally, ice serves as both a resource for ISRU and a science target as it preserves indicators of past environmental conditions, plus also preserves potential biosignatures.
  - Sample Handling – curation and sample return
    - Why - Samples collected during or after human presence will record human influence on Mars environment. Proper documentation, handling and curation is critical to minimize this influence, as well as minimize concerns regarding planetary protection (both forward and back contamination).

2c. Development Plans: Fundamental and Applied Research

- Fundamental and applied research
  - Environmental monitoring
    - Strategies/Policies – Long-term strategy for deployment of monitoring stations in place prior to human arrival is preferred to maximize science value of human exploration.
    - Technologies – Buildup of hardware and structures must consider local environmental conditions, look to experiences from buildup of Antarctic facilities and research program, must focus on network of instrumentation
  - ISRU processing (overlap with Mars Surface Power)
    - Strategies/Policies – Strategy must be developed to ensure proper handling of resources without erasing science value or exposing crew to toxic and hazardous conditions/environments. (Arctic research programs deal with similar goal integration issues)
    - Technologies – Develop waste management technologies that minimize, and monitoring capabilities that characterize, the impact to the local environment.
  - Sample Handling – curation and sample return
    - Strategies/Policies – Sample handling plan must be developed that involves in-situ and in hab/lab analyses, with intention for identification of sample return to Earth. Good preliminary research from DRATS and HERA, must continue to develop sample handling strategy. Lunar sample acquisition & curation review (LEAG-CAPTEM, 2010) – Suggest MEPAG-type SAG with CAPTEM on human sample selection, curation, handling
    - Technologies – Develop bio-level sample isolation facilities to operate on the Martian surface **IF** policy enables human interaction with such materials, or establish protocols for operations following unexpected encounter with those materials. Tools and in-situ instruments for clean collection and triage for identifying samples to be isolated and returned to Earth. Development of instruments for Mars system analyses of splits from return samples (relevant to Strategy, decide how much data analysis and processing will be conducted by crew, or will they only focus on sample collection and sample analysis while data processing and analysis is conducted on Earth by Science Team)

1d. Sub-Pole: Surface Habitability

- Surface habitability
  - Adequate volume for crew, supplies (crew consumables, supplies, commodities buffer [e.g., water, gases, etc.], spares TBD other)
  - Interior layouts
  - Repair techniques and tools
  - Individual workstation design
  - Lighting architecture to augment natural environment
  - Research disciplines included in the habitat and level of functionality for each
  - Hatch size and docking system
  - Crew size
- Why are these a Tall Pole? Why are they Challenging?
  - Limited human expertise in long duration, remote locations – no science to predict the volumes, layouts, tools, etc. needed
    - Some pseudo-analogs exist (e.g. Antarctic, submarines, small surface vessels, aircraft) but many differences between those environments and deep space vehicles
      - Example: Submarines – small crew quarters, but large crew size and numerous/diverse facilities, plus periodic surfacing and ocean access
      - Example: Antarctic – deep isolation, but evacuation possible and access to large surface areas outside habitat
      - Example: ISS – similar mission durations, but wider breadth of science functionality and <1 day evacuation to Earth plus resupply during crew expedition
  - Human behavior is non-deterministic and difficult to predict
  - Each space flight mission is a custom solution
  - Gap: *We have no validation that a 30 day test extrapolates to a 1000 day test or mission*

2d. Development Plans: Surface Habitability

- Tall Pole can be addressed via experimental design and testing – analog missions to test/validate predictive models and explore nominal and off-nominal conditions
- Strategy - for analog testing (at existing or future analog facilities)
  - Conduct mission simulations with relevant Mars mission durations in multiple existing and future analog facilities to identify trends or relationships impacting Mars surface habitat design with respect to volume, layout, workstation design, crew size, hatch size & docking system, work (science, ISRU, technology testing, robotics, etc.) disciplines included, and repair techniques and tools.
  - Key Test Elements
    - Maintenance, Repair, and Fabrication
      - Planned and unplanned activity (habitat, spacesuits, other surface elements)
      - Time-critical subsystem repairs
      - Component vs, raw material vs. ORU sparing
    - Preventative and Emergency Medical Care
      - Consumables mass/volume/access implications
      - Long term recovery
    - (continued …)

2d. Development Plans: Surface Habitability

- Strategy - for analog testing (at existing or future analog facilities) - continued

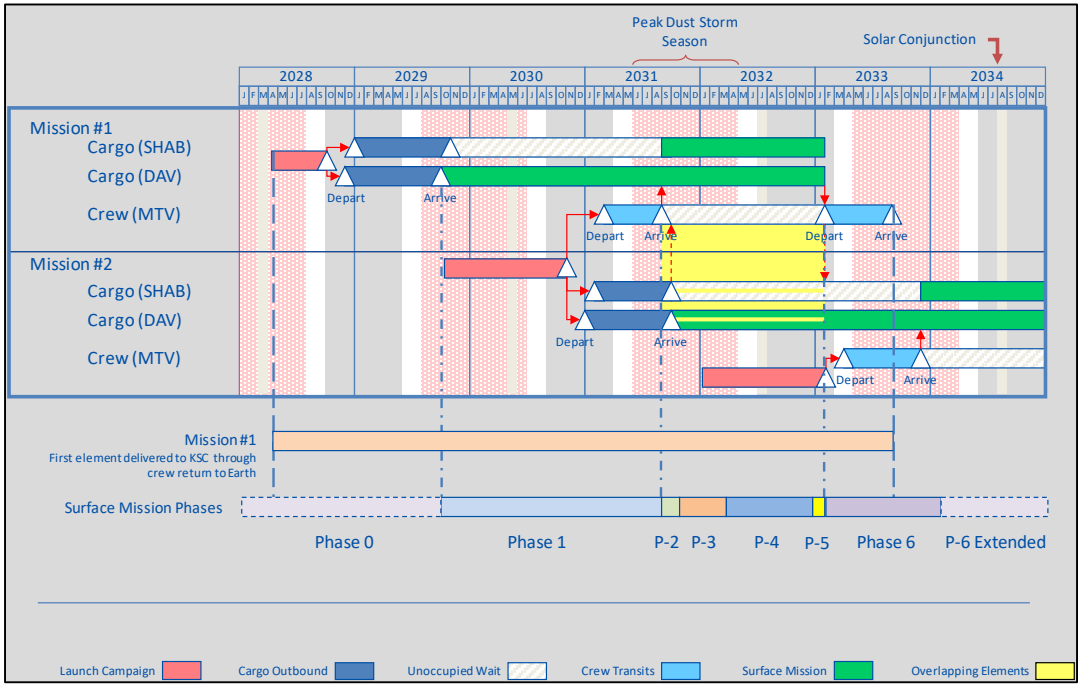
  Key Test Elements
  - Long Term Habitation
    - "Habitat Quality"
    - Crew Psychology/Teaming
    - Logistics Translations (including across hatches)
    - Transitions across habitable elements (lander, habitat, rover)
  - Meaningful Crew Work
    - Degree of Crew Scheduling Authority / Mission Design
    - Manpower Assessment
    - Work Disciplines (Science, ISRU, Technology Testing, Robotics, etc.)
      - Quality and quantity of work achieved in each domain
- Technologies
  - Repair and fabrication tools and interfaces
  - Medical tools and interfaces
  - Lighting
  - User interfaces and displays
  - Habitat modeling/sizing tools
  - Surface docking systems

1e. Sub-Pole: Dormancy and Startup

- Initial startup before crew arrival, followed by extended periods of dormancy (100s of days to a few years) followed by reliable re-startup and operations (100s of days to a few years)
  - Initial startup of systems in partial g after long duration 0g environment
  - Initial inspection (external and internal) after delivery to Mars surface
  - If multiple habitation elements are required, verification of successful offloading and docking for initial startup
  - Impact of dormancy on reliability (over time) of subsystems within the habitat
  - Particular impact of dormancy to those systems relying on fluids (e.g., ECLSS)
  - Internal subsystems that are vulnerable to temperature extremes
  - Monitoring internal (and external ?) biological environment between human visits
  - After first human visit, how do you continue the “science” piece of mission that requires habitat (IVA) systems ?
  - What is minimum power requirement during dormancy?

Representative Mission Phases

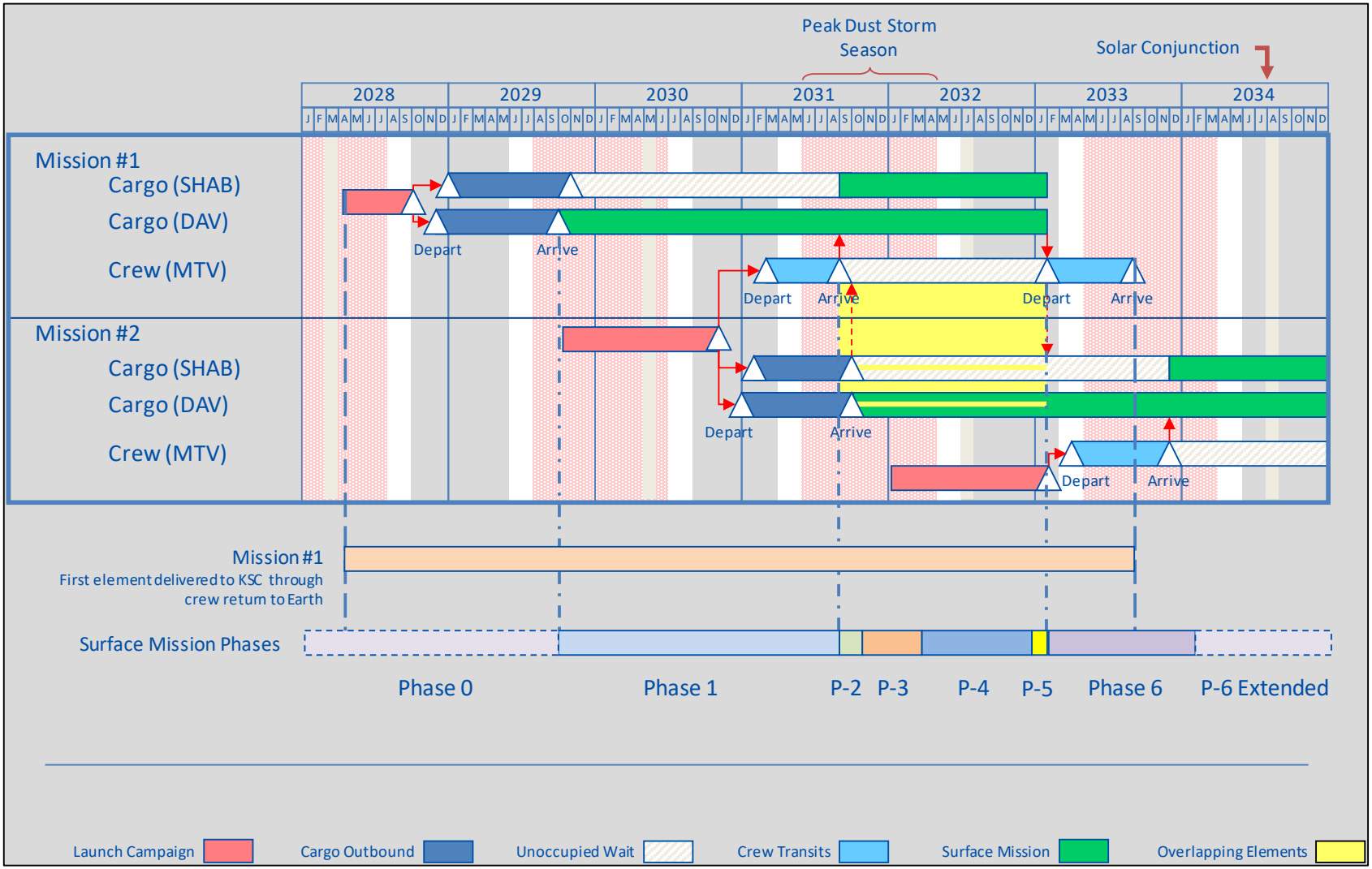
- **Phase 0 – Prior to Cargo Landing**
  - Observations and investigations of the landing site by previously deployed orbital and surface assets
  - Characterize habitability, including potential special regions
- **Phase 1 – Post Cargo Landing (~2.25 Years)**
  - Cargo Landing
  - FSPS and ISRU deployment
  - Exploration by robotic assets, micro-climate monitoring
  - Final crewed landing site selection
- **Phase 2 – Crew Landing & Acclimation (~30 Sols)**
  - Crew Landing and acclimation to Mars gravity environment
  - Additional deployment of assets and local science investigations as time and capabilities permit
- **Phase 3 – Local Exploration (~30 Sols)**
  - EVAs within local area (~10 km) to set up central stations and complete initial science objectives
  - Deployment of Deep drill system
- **Phase 4 – Regional Exploration (~410 Sols)**
  - Up to 19 separate 15-sol traverses with 2 SPRs
  - Mobility extends up to ~200 km from landing site
  - Sample analysis and follow-on local investigations continue
- **Phase 5 – Preparation for Ascent (~30 Sols)**
  - Final curation of samples and preparation of MAV
  - Crewed Launch with contingency window
- **Phase 6 – Post Crew Departure**
  - Robotic assets continue exploration

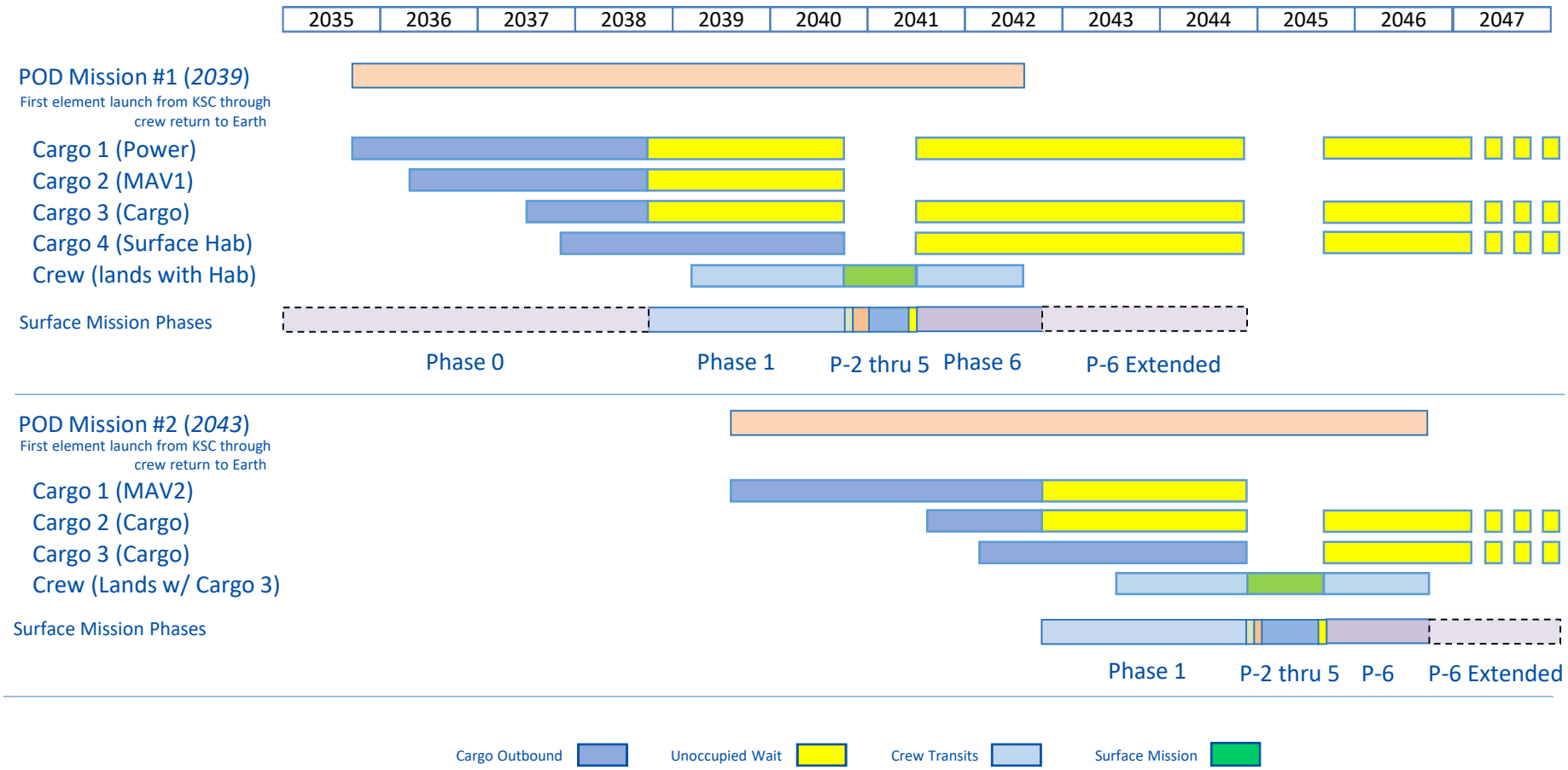


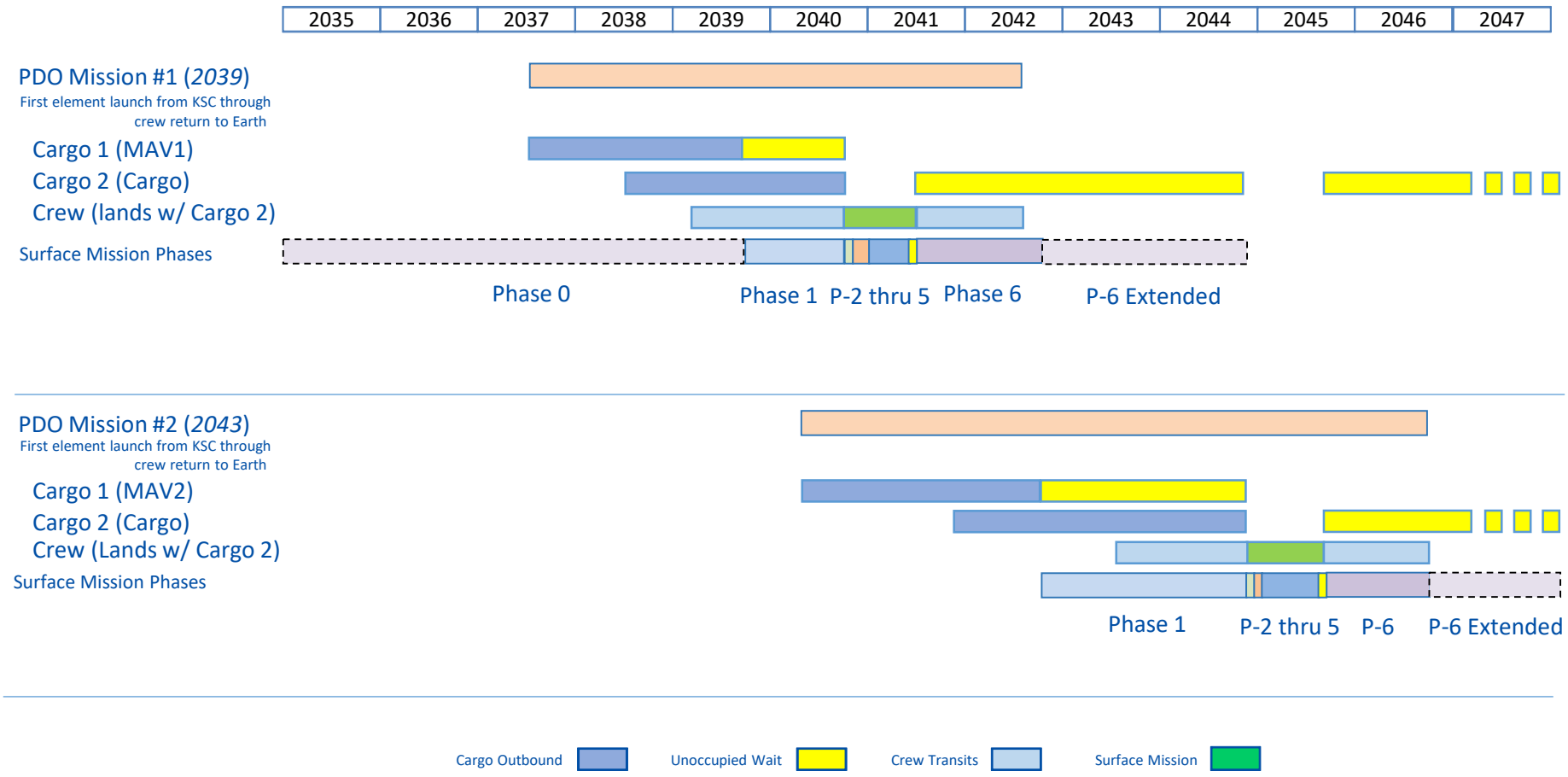
The figure above illustrates the relative sequence of each phase with trajectory data for a Mars surface mission set to occur in the early 2030 time frame.

Each mission will:

- Prepare a surface mission plan based on the objectives set for the EZ
- Customize the mission plan based on discoveries made and lessons learned by previous crews
- Develop a science payload (1000 kg allocated) based on the customized mission plan


Peak Dust Storm Season
Solar Conjunction
2028
2029
2030
2031
2032
2033
2034
J F M A M J J A S O N D
Mission #1
Cargo (SHAB)
Cargo (DAV)
Crew (MTV)
Depart
Arrive
Mission #2
Cargo (SHAB)
Cargo (DAV)
Crew (MTV)
Mission #1
First element delivered to KSC through crew return to Earth
Surface Mission Phases
Phase 0
Phase 1
P-2
P-3
P-4
P-5
Phase 6
P-6 Extended
Launch Campaign
Cargo Outbound
Unoccupied Wait
Crew Transits
Surface Mission
Overlapping Elements


2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
POD Mission #1 (2039)
First element launch from KSC through crew return to Earth
Cargo 1 (Power)
Cargo 2 (MAV1)
Cargo 3 (Cargo)
Cargo 4 (Surface Hab)
Crew (lands with Hab)
Surface Mission Phases
Phase 0
Phase 1
P-2 thru 5
Phase 6
P-6 Extended
POD Mission #2 (2043)
First element launch from KSC through crew return to Earth
Cargo 1 (MAV2)
Cargo 2 (Cargo)
Cargo 3 (Cargo)
Crew (Lands w/ Cargo 3)
Surface Mission Phases
Phase 1
P-2 thru 5
P-6
P-6 Extended
Cargo Outbound
Unoccupied Wait
Crew Transits
Surface Mission


2035
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2047
PDO Mission #1 (2039)
First element launch from KSC through crew return to Earth
Cargo 1 (MAV1)
Cargo 2 (Cargo)
Crew (lands w/ Cargo 2)
Surface Mission Phases
Phase 0
Phase 1
P-2 thru 5
Phase 6
P-6 Extended
PDO Mission #2 (2043)
First element launch from KSC through crew return to Earth
Cargo 1 (MAV2)
Cargo 2 (Cargo)
Crew (Lands w/ Cargo 2)
Surface Mission Phases
Phase 1
P-2 thru 5
P-6
P-6 Extended
Cargo Outbound
Unoccupied Wait
Crew Transits
Surface Mission

2e. Development Plans: Dormancy and Startup

- Strategies/Policies - (similar to surface habitability) conduct mission simulations with relevant Mars mission durations in multiple existing and future analog facilities
- Technologies
  - Monitoring systems
  - Inspection systems
- Developers: NASA, aerospace industry (?).
- Demonstrations: ground and cislunar(?) testing of desired technologies and operational procedures
- Expected time to close: 10-15 years
- Need date: late 2020s – early 2030s.
- Acceleration strategies: TBD

3. Gaps, shortcomings or missing elements

- Captured above (not repeated here)
- Observation: in addition to technological challenges and gaps, there are a significant number of strategy and policy gaps that could be (in some cases, must be) developed before decisions and progress can be made in technological or architectural aspects of human Mars missions.

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